Case Studies of Energy Information Systems and Related Technology: Operational Practices, Costs, and Benefits

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ABSTRACT

Energy Information Systems (EIS), which can monitor and analyze building energy consumption and related data throughout the Internet, have been increasing in use over the last decade. Though EIS developers describe the capabilities, costs, and benefits of EIS, many of these descriptions are idealized and often insufficient for potential users to evaluate cost, benefit and operational usefulness. LBNL has conducted a series of case studies of existing EIS and related technology installations. This study explored the following questions:

- How is the EIS used in day-to-day operation?
- What are the costs and benefits of an EIS?
- Where do the energy savings come from?

This paper reviews the process of these technologies from installation through energy management practice. The study is based on interviews with operators and energy managers who use EIS. Analysis of energy data trended by EIS and utility bills was also conducted to measure the benefit. This paper explores common uses and findings to identify energy savings attributable to EIS, and discusses non-energy benefits as well. This paper also addresses technologies related to EIS that have been demonstrated and evaluated by LBNL.

Introduction

This paper begins with a summary of background research and a definition of Energy Information Systems. The main part of the paper is a case study of the use of an EIS at a large campus. The case study includes a description of the system, daily operations and findings from the EIS, energy savings, and a cost-benefit analysis. It is followed by a short description of case studies of technologies related to EIS.

Background

Several past studies have demonstrated that building energy usage can be reduced by 5% to 20% or more by identifying and correcting operational issues (Claridge, et al., 1998; Gregerson, 1997). This process, often referred to as Retro-Commissioning, requires an expert commissioning engineer (Claridge, 1994). However, by installing robust performance monitoring tools, many building operators and energy managers can identify and correct problems by themselves. LBNL has been evaluating building monitoring and control technologies to understand how the operational improvements and energy savings can be achieved by building operators and energy managers. References to previous work are included in this paper. Energy Information Systems (EIS) are an example of technologies that can help operators reduce energy use by understanding hourly load profile and equipment schedules. LBNL has conducted reviews of 17 EIS and diagnostic tools that focus on technical descriptions and classifications of EIS technologies and markets (Motegi, et al., 2003; Friedman, et al., 2001).

Energy Information Systems

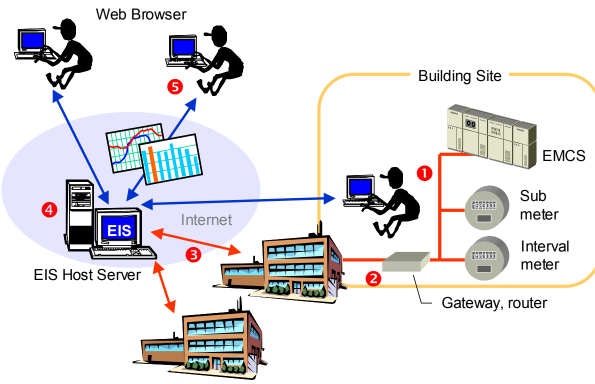
Energy Information Systems (EIS) refer to software, data acquisition hardware, and communication systems that provide energy information to commercial building energy managers, facility managers, financial managers and electric utilities. Though EIS has wide variety of uses and capabilities, the basic features of EIS are:

- Monitoring and collection of energy data

- User-friendly web browser interface accessible from anywhere via Internet
- Visualization of the time-series data
- Tools to assist in understanding energy consumption trends and energy saving opportunities

Figure 1 shows the typical system architecture of an EIS. The primary use of an EIS is to assist facility operators, owners, and other decision-makers in managing building energy use. Real-time or daily updating of hourly energy consumption data allows users to evaluate building energy performances that are otherwise difficult to observe. Since most EIS products provide real-time or daily updates of hourly trend data, facility operators can verify the impact of a change in an operational strategy immediately following or within a day of the action. In the absence of an EIS, an impact evaluation would have to be postponed until the monthly utility bill has arrived. Besides, utility bills will only reflect significant operational changes. It is also difficult to attribute a reduction (or increase) in utility bill to a specific action taken on a building.

Besides the basic capabilities of EIS mentioned above, there are varying objectives and functionalities among different EIS products. To cope with electricity reliability problems in recent years, major utility companies have created new demand response (DR) programs that offer customers financial incentives for reducing peak loads. To make the DR programs feasible and efficient, utility companies adopted and promoted EIS products as communication systems between utilities and their customers. In addition, control system developers have expanded accessibility of energy management and control systems (EMCS) to monitor and control facilities through a web browser with a user-friendly interface.



(1) Data are collected at the building
(2) A communication device dispatches data
(3) The data is sent to a database server via Internet.
(4) The database server stores and archives the data
(5) EIS users access the server remotely by a web browser

Figure 1. Typical Architecture of an EIS

Case Studies

This study includes three performance monitoring systems;

Case Study 1: **Enterprise Energy Management Suite™ (EEM Suite, fully commercialized)**
Case Study 2: **Information Monitoring and Diagnostic Systems (IMDS, research oriented)**
Case Study 3 **General Services Administration Energy and Maintenance Network (GEMnet, under development)**

Table 1 summarizes the characteristics of the four case study sites. The University of California, Santa

Table 1. Summary of Case Study Sites

	Case Study 1	Case Study 2		Case Study 3
Site	**University of California, Santa Barbara (UCSB)**	**Hong Kong Bank Building (160 Sansome)**	**Park Executive Office Building (925 L St.)**	**GSA Pacific-Rim Region (Region 9)**
Location	Santa Barbara, CA	San Francisco, CA	Sacramento, CA	CA, NV, AZ
Size [ft^2]	4,554,479 (3,200~3,800K for maintained area)	100,000 (18 floors)	175,000 (14 floors)	5,551,000
Type	University campus 35 buildings	Office Single building	Office Single building	Office, public services 13 buildings
# of operators	12 staff members for 4 zones	1 chief operator 1 facility manager 1 contractor	1 operator 1 energy manager	1 to 5 operators per site 2 regional manager, etc.
Year built	1960s ~	1966	1970	
Technology	EEM Suite™	IMDS	IMDS	GEMnet
Installation Date	June 2001	May 1998	August 2002	2001

Barbara (UCSB) case study is featured in detail in this paper because it is an example of high-end EIS. The other case studies are summarized briefly here and in detail in other publications. The cases studies are based on interviews with both EIS developers and end users including energy managers and operators.

Case Study 1: UC Santa Barbara

The University of California, Santa Barbara (UCSB) has 4.5 million square feet of building area, holding approximately 22,000 students, faculty, and staff. The electric energy use intensity (EUI) of the campus in 2001 was 16 kWh/sqft-yr, or 55 kBtu/sqft-yr, and the gas EUI was 56 kBtu/sqft-yr (111 kBtu/sqft-yr in total). UCSB has been proactive in energy conservation measures including energy-efficient retrofits, operation and maintenance optimization, and energy-efficient new construction. The energy manager is concerned with broad energy and environmental issues, and is eager to reduce campus energy usage. UCSB was selected as a case study site because of its dedication to energy conservation and active use of the EIS.

All campus buildings are controlled by a central EMCS. The EMCS has an onsite user workstation which is installed at the facility office, and an LCD-monitor controller at each zone. The EMCS interface provides real-time data and simple time-series visualization of all monitored points, and controls operational settings, but it does not have a web interface.

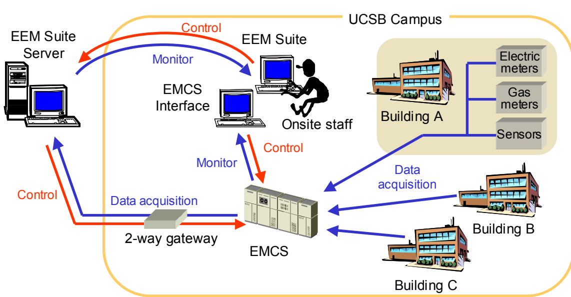


Figure 2. EEM Suite™ at UCSB

The EIS was installed in 2001 as a part of an energy conservation project. Figure 2 shows the system architecture of UCSB's EIS, EEM Suite™. EEM Suite™ is a web-based energy analysis tool for monitoring and analyzing building data with the use of various graphical charts. EEM Suite™ has a number of functions to analyze whole building energy consumption and energy cost data for multiple buildings. It can also track component-level data to help operators conduct more detailed system diagnostics.

A two-way gateway system was installed on the EMCS, enabling the EIS to retrieve monitored data from the EMCS. UCSB energy staff also installed a number of new electric meters and gas meters and connected them to the EMCS and the EIS. The EIS is capable of sending control signals to the EMCS via the Internet. Implementation of web-based control function is planned for future demand reduction activities.

EIS Costs

Table 2 shows the cost of installing EEM Suite™ at UCSB. The costs shown in the table are the initial proposal from the developer, that were discounted by the developer because of the strategic partnership between UCSB and the developer. UCSB energy staff also installed numerous new electric and gas meters. The approximate costs of extra metering was about $50,000 for about 30 electric meters and integration of about 20 gas meters. Other IT and computer costs are $11,614 per year. The cost to UCSB was offset by $226,000 in public funding.[1]

Table 2. Cost of EEM Suite™ at UCSB

Component	Cost
Software license EEM Suite™ Additional modules **Total**	 $84,000 $97,000 **$181,000**
Hardware EMCS two-way gateway	 **$12,000**
Additional Sensors	**$50,000**
Installation/setup	**$52,000**
Annual maintenance and support (18% of software license fee)	**$35,000**
Networking	**$11,500**
Grand Total	**$341,500**

EIS Operations

The EIS and EMCS interface are used by one energy manager, one facility manager, and several zone managers. The energy manager and the facility manager are responsible for campus energy management and routinely use both the EIS and the EMCS interfaces. The zone managers are responsible for system operations and trouble shooting for the

[1] UCSB received Senate Bill (SB) 5X funding from the California Energy Commission. SB5X was passed by the California Legislature in 2001 and provided funds for the installation of demand responsive software and hardware.

buildings in their zones. Upon occupant complaints, the zone managers would check the operational status using the EMCS interfaces located in each building, and modify set points if necessary. The zone managers rarely access the EIS because they are not responsible for energy management and the EMCS interface provides sufficient information for their purposes.

The first version of EEM Suite™ was installed on the campus in the Summer 2001. The energy manager spends at least 30 minutes per day using the system, and often more when operational settings have been changed. He is also able to access the data from home at any time.

The energy manager inspects time-series energy consumption data as part of his daily routine. Scatter plots are used to see the correlation between natural gas/chilled water consumptions and the outside air temperature. The building operation pattern has to be clearly understood since chilled water usage varies depending on operational schedules. If a zone manager doesn't inform him of changes in operation, data that appear as outliers provide feedback that something unusual is going on.

The energy manager finds the data summarization features useful. He can view energy usage by square footage for each building, to identify which building is the most energy-intensive. Unlike the EMCS, time series functions show hourly, daily, weekly, and monthly summation. Daily total electricity consumption usually has a stronger correlation with weather than hourly usage. The reporting features also support participation in energy conservation programs for assistance in preparing information quickly. The analysis functions help illustrate which buildings achieved energy reductions, when and how much reduction has been accomplished, and which energy conservation measures contributed to the reduction.

Overall, the energy manager concluded that if the facility did not have someone proactive to analyze the data, the EIS would be useless. If you can't measure it, you can't manage it. The energy manger and his staff find the EIS invaluable for their current energy projects.

Findings from the EIS

UCSB has many laboratory buildings that are more energy-intensive and have longer operating schedules than the average campus building. EEM Suite™ has been useful in identifying system malfunctions and suspicious energy consumption patterns. The retrofit projects were targeted at the buildings that had the worst energy performance. Though the energy manager had a general sense of which buildings had high energy use, the EIS was helpful in quantifying the benefits of retrofits.

Opportunities for energy savings through operational changes have been found in the daily routine of browsing time series data on the EIS. Below are some examples of energy saving opportunities found with EEM Suite™.

<u>Physical Science Building: Fan Nighttime Reduction</u>
Immediately after the EEM Suite™ was installed in May 2001, the facility manager found that the whole building electricity load profile for the Physical Science Building (110,000 sqft) was flat. The energy manager thought it might be an anomaly, but the next day the high baseline persisted. The energy manager found the supply and exhaust fans (262 kW in total) were operated 24 hours everyday at 100% load, even though the building is not occupied at night. Although the control system should have had a nighttime setback strategy, the building staff disabled the setback and left the fan on at night to ensure good air quality.

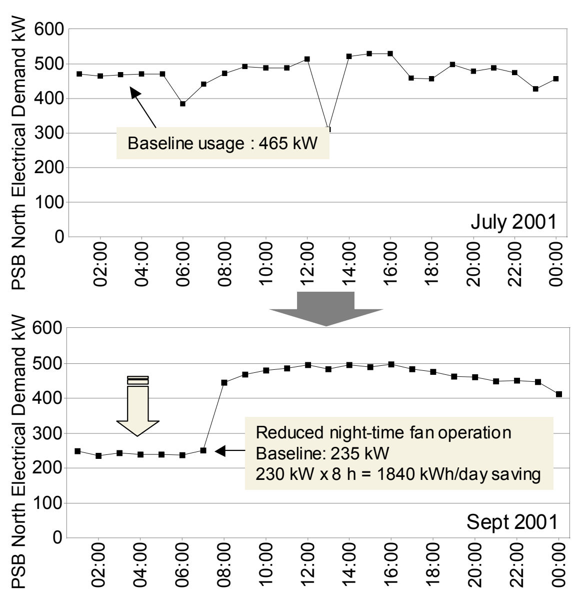


Figure 3. Phys. Sc. Building Electrical Demand

The energy manager consulted the building staff and convinced them to reduce the fan operation speed down to 50% between 12 am and 7 am. Because this building requires 100% outside air, this airflow reduction contributes to significant energy saving in space heating and cooling. The problem was remedied in August 2001. Figure 3 shows the average weekday 24-hour load shape of the whole building electricity use for July 2001 (before the remedy) and September 2001 (after the remedy). This change has saved 1840 kWh per day, or about \$92 per day[2]. When winter gas saving for space heating is considered, the total energy and cost savings become larger, but it was not quantified.

Fume Hood Position

The energy manager found that fume hoods in the Chemistry Building were left open at night when they were not used. He asked the occupants to close the fume hood. To verify the change, the energy manager trended the average fume hood position. The energy manager found the average fume hood sash position was 30% open every night. Figure 4 shows times-series trend of average fume hood position.

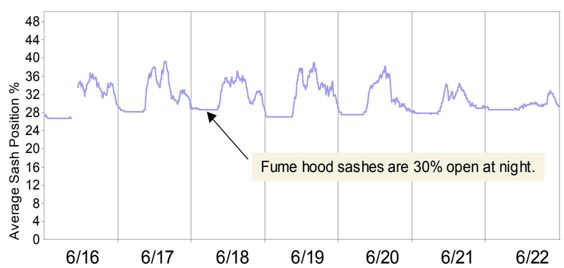


Figure 4. Average Fume Hood Position

The energy manager currently has students walking through the building and closing sashes where possible. They have also posted new signs at each fume hood reminding people to close the sashes. However, minimizing the sash position is a constant challenge. Although the problem could be remedied temporary, it rarely persisted.

Recreation Center Pool Gas Consumption

The Recreation Center has two outdoor pools. Gas consumption for pool water heating was found to be unusually high on 3/17/2003, given that the outside air temperature was same as the previous few days. Another suspicious trend was that the water temperature of Pool A dropped from 83ºF to 79ºF, from 5 PM on the 16th to 8 AM on the 17th, while the temperature is usually kept higher than 81ºF. The energy manager discovered that the Recreation Center staff forgot to cover the pool at night, causing an increase in heat loss from pool water. The increased gas consumption was about 40,000 cu ft, which costs \$280 per night. Figure 5 shows daily gas consumption of the Recreation Center and time-series temperature trend of the pools and outside air (OAT).

[2] Simply estimated by \$0.05/kWh.

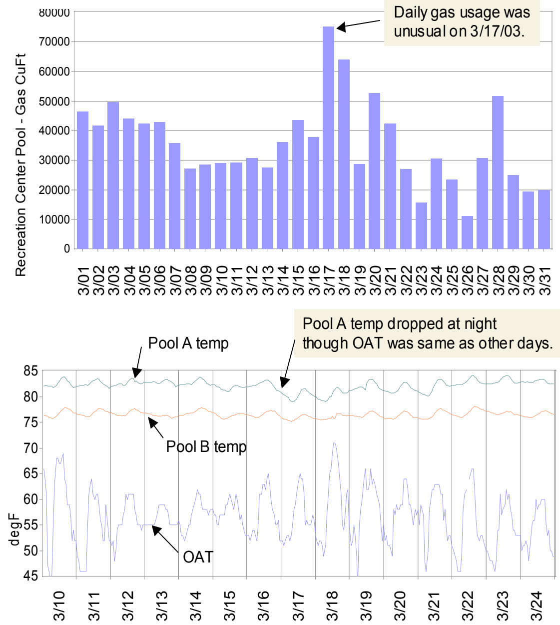


Figure 5. Pool Gas Consumption, Water Temp.

Energy Savings

The annual energy usage has declined since 1998. Electricity usage in 2002 was 24.1% lower than in 1998. Considering that campus floor area increased by 112,411 ft^2 (2.5%) from 1998 to 2002, the electric EUI was reduced from 18.8 kWh/ft^2-yr in 1998 to 14.0 kWh/ft^2-yr in 2002, a 25.9% reduction. Figure 6 shows monthly electricity usage of whole campus in each year from 1999 to 2003.

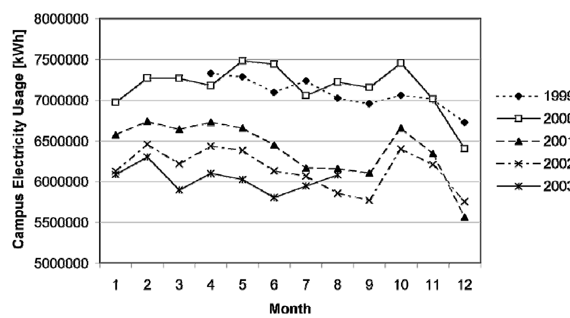


Figure 6. Campus Monthly Electricity Usage

EEM Suite™ was installed in May 2001. Electricity usage in Summer 2001 (from June through September) was 4,000 MWh (13.8%) less than in Summer 2000. Electrical peak demand was reduced by 16.0%, and natural gas usage was reduced by 10.0%. Table 3 summarizes the summer energy reduction (Dewey, 2002).

Table 3. Summer Energy Reduction

	2000 June-Sept	2001 June-Sept	Reduction
Electricity [MWH]	29,000	25,000	4,000 (13.8%)
Peak demand [kW]	14,800	12,600	2,200 (16.0%)
Natural gas [Therm]	63,900	57,500	6,400 (10.0%)

The reduction in energy consumption is a result of major system retrofits and operational optimization. The major system retrofits include virtual central plant[3] and high-efficiency lighting, which achieved roughly 50% of the total savings. Another 50% came from operational optimization such as reducing night-time fan and lighting energy, optimizing fume hood sash positions, and optimizing economizer operation. EEM Suite™ has been helpful for the operational optimization. Unlike the energy-efficiency retrofits, the EEM Suite™ itself doesn't save any energy unless the energy managers utilize it and take action.

2001 Demand Relief Program

UCSB has conducted several demand relief tests to evaluate their potential demand reduction. The first test involved only building occupant effort. The conservation strategies included turning off unnecessary lighting, shutting down unused equipment, and enabling energy saving modes on printers, copies, and computers. This test was executed on May 9th, 2001, and reduced demand by 730 kW (6.5%)[4]. Facility staff conducted the second test. The strategies included shedding load on the virtual chilled water loop, curtailing individual chiller loads, curtailing boiler systems, and capping air volume on VAV air handlers. This test reduced load by 1090 kW (9.7%). The third test was combination of these two modes, and conducted over a week (5 days). For this test, demand reduction actions were automatically initialized by the EIS. This test resulted in an average 1585 kW (14.1%) demand savings each day.

On July 3rd, 2001, California Independent System Operator (ISO) called a demand curtailment event. UCSB participated in this event, and achieved 629 kW of demand reduction (6.1%). On July 27th, the energy manager conducted a DR program operational test using the EIS. This test was initiated and the result was calculated by EEM Suite™. The result shows 1160 kW of demand reduction (11.4%). Although the facility was prepared for multiple DR emergencies, only one event occurred in this summer. Table 4 summarizes results of the series of DR demonstrations.

Table 4. DRP Demonstration Results

	Date	Duration	Peak demand reduction*
Building occupants	5/9	11:00-15:00	730 (6.5%)
Physical facility	5/11	11:30-17:30	1090 (9.7%)
Combined**	5/21~25	11:00-15:00	1585 (14.1%)
ISO	7/3	14:00-18:00	629 (6.1%)
EIS test	7/27	12:00-16:00	1160 (11.4%)

* Average of previous 10-weekday is used as the baseline. Peak demand reduction is average during the shed duration.
** Peak demand reduction is average of the 5 days.

Benefits Analysis

The benefits of EIS can be separated into (1) energy savings, (2) peak electric demand reduction savings, and (3) human resources savings. Energy savings include the costs of electricity and gas saved by operational changes directed by the EIS. The demand reduction savings include the costs saved by reduction of peak electric demand charge and additional incentives received for participation in a demand reduction program. The human resource savings include the costs saved by reducing the number of hours worked by staff members.

Table 5. Energy Cost Saving

	Electricity [MWH]	Peak demand [kW]*	Total
May00–April01	83,700	12,742	
May01–April02	75,100	11,362	
Saving	8,600	1,300	
Cost saved	$430,000 (10.3%)	$160,000 (12.4%)	$590,000 (10.8%)
Due to EIS (50%)	$215,000	$80,000	$295,000

* Peak demand [kW] shows average of 12 months. Saved cost shows annual total.

Table 5 summarizes the campus energy cost savings between May-2000-to-April-2001 period and May-2001-to-April-2002 period. The cost savings were estimated by applying $0.05/kWh for electricity consumption and $13/kW (June to September, $6/kW in other months) for monthly demand charge. As a result, the electricity cost savings were $430,000 and the demand cost savings were $160,000. Based on the energy manager's insight that 50% of energy savings came from operational optimization helped by the EIS, the total energy cost savings attributable to the EIS were $295,000 for the first year, resulting in an estimated payback period of 1.2 years. UCSB

[3] USCB campus buildings are connected by a chilled water loop. This chilled water loop reduces the total capacity of the campus cooling systems. It also increases chiller efficiency when the demand is low by operating more chillers at a higher load, instead of operating all chillers at low loads.
[4] The kW reduction was estimated by subtracting actual kW demand from average of previous 10-weekday.

also received $77,000 for its participation in the California ISO's Summer 2001 Demand Relief Program. Although the program is no longer available, the payback period with the DRP payment was less than 1 year.

The energy manager and the facility manager saved a significant amount of time and effort evaluating their energy projects and compiling reports. They now have additional time to communicate with building occupants more closely and to plan future energy saving projects. Unlike the cost savings, these benefits cannot be easily quantified.

Case Study 2: 160 Sansome, 925 L

The IMDS (Information Monitoring and Diagnostic System) was developed and evaluated as a collaborative effort among researchers, building property managers, and private industry. The IMDS consists of a set of high-quality sensors, data acquisition software and hardware, and data visualization software, including a web-based remote access system.

While a typical EIS focuses on whole building energy management for a single or multiple buildings, IMDS focuses on building system and component level of diagnosis. The IMDS's trending points include component-level electricity consumption data and many other data types that are typically not available from an EMCS such as an equipment electric demand. The data trended by the high-quality sensors in short intervals (1 minute) is desirable to detect various system malfunctions and failures.

The IMDS demonstration sites were carefully chosen based on the innovativeness of the on-site staff. These demonstrations were intended to illustrate the value of high quality performance monitoring systems to innovative building operators. Both of the two IMDS demonstration sites were office building operated by third party property management firms where tenants pay the electricity costs. In both sites we found strong interests by the operators to minimize energy use although they did not directly reduce their companies costs with such savings.

Initial IMDS Case Study: 160 Sansome

160 Sansome (San Francisco, CA) was the first IMDS demonstration site. The first generation of IMDS at 160 Sansome consists of Enflex™[5] as the data acquisition system and Electric Eye™[6] as the web-based data visualization software. In the research stage, the IMDS was only used for monitoring and diagnostics. After one year of evaluation, a control system retrofit was started based on findings from the IMDS. The control capability of Enflex™, which was previously not utilized, was used as the main control system, replacing the old EMCS. Figure 7 shows a system diagram of the 160 Sansome IMDS after the EMCS retrofit.

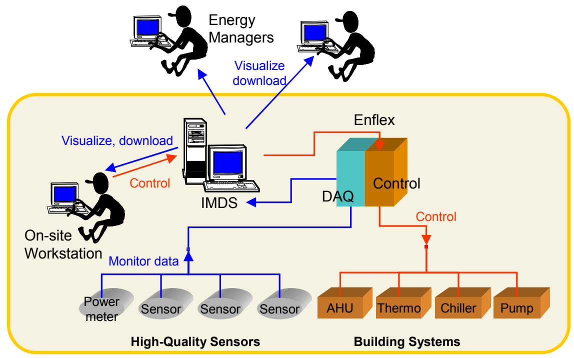


Figure 7. IMDS at 160 Sansome (after EMCS retrofit)

The IMDS has been useful in identifying operational problems resulting from limitations of the old EMCS, such as chiller false start, inappropriate morning warm-up, supply air flow misleading, frequent oscillation of fan power, and unnecessary dual-pump operation. The operations staff implemented a series of changes in control strategy based on findings from the IMDS. As a result, complaint calls have been remarkably reduced. Furthermore, following the controls retrofit based on the IMDS technology platform, Smothers and Kinney reported that electricity use dropped 12% and gas use dropped by 19% worth about $40,000 per year. (Piette, et al., 2000; Smothers and Kinney, 2002).

2nd IMDS Case Study: 925 L Street

925 L Street (Sacramento, CA) was the second demonstration site for the IMDS. The overall goals of this project were to refine the IMDS concept and to assess the value and usefulness of the IMDS in a

[5] Two-way gateway device. Retrieve/archive data, and receive/send control signals.

[6] Electric Eye™ was originally developed for use with a high-end graphical workstation and now runs on PCs using the Linux operating system. The software is quite powerful, allowing one to examine large data sets. It is possible to manipulate and display more than a year of one-minute data from up to eight points simultaneously.

more general context. One difference between this site and the first demonstration site was that the existing EMCS of 925L was far more sophisticated than the pre-retrofit EMCS of 160 Sansome. This project addressed the question as to whether the IMDS was essential to achieve the benefits that 160 Sansome had achieved, in other words, whether a modern EMCS could have achieved the same benefits as the IMDS. This project evaluated an acceptable level of sensors, and data collection and visualization systems. The sensors and monitoring systems were selected from a broad spectrum of capabilities at varying costs. Standard commercial-grade sensors were used where higher accuracy sensors did not provide extra value in the pilot IMDS installation.

Initially, as part of his daily routine, the chief engineer used the “Operator Page”, which is customized to provide most of the system data he needs to fill in his daily activity logs and system status report. This function helps him quickly verify if the controls are operating correctly. After a few months of operation, the chief engineer started to utilize the data visualization capabilities of IMDS as a part of his daily routine. The also operators reported that the IMDS data is far more accurate than on the EMCS because of the quality of the sensors, their location, and their recent commissioning of the sensors. As a result, they monitor the building operation with readings from the IMDS and implement the control changes on the existing EMCS terminal. The operators are planning to use the IMDS to obtain information to develop a capital budget for HVAC system upgrades (Piette, et al., 2003).

Case Study 3: GSA Region 9

The US General Services Administration Pacific Rim Region (Region 9) manages over 20 million gross square feet of federally owned office space, plus additional leased office space. To assist the real estate management the Pacific Rim Region is developing GEMnet (GSA Energy and Maintenance Network). GEMnet is a collection of information technology initiatives, including computerized maintenance management systems (CMMS) to efficiently manage maintenance work orders, and remote monitoring and control systems to reduce operational costs by improving energy efficiency and reducing peak demand. Ultimately the various systems will use a common database platform. Figure 8 shows the system diagram of GEMnet. Key features of GEMnet are described below.

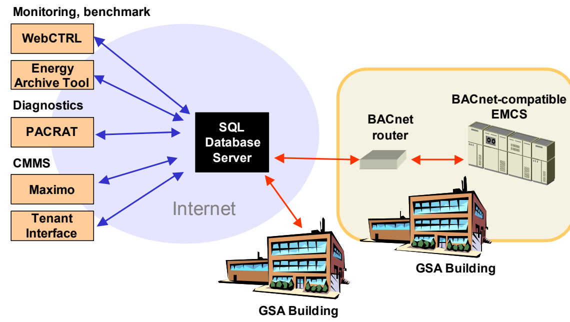


Figure 8. GEMnet

<u>CMMS</u>

CMMS (Computerized Maintenance Management System) software maintains a schedule for preventive maintenance on building equipment. The CMMS in GEMnet is a combination of several applications. Maximo™, the preventive maintenance software, creates work orders based on the equipment lifetime and maintains a history of all work done. GEMnet uses a customized function of Maximo™ where users, including tenants, may enter work order requests through the web page. GSA is currently developing a function to create CMMS work orders based on building automation system alarms. The interface will create work orders, e-mails or pages to responsible parties depending on the type of alarm and the settings in the alarm description.

Another innovation that GEMnet is developing is an interface that will allow tenants to directly enter service call data. This effort will include a live tenant interface to inform tenants of activities that may affect HVAC or related services within the building (Levi, et al., 2002; Federspiel and Villefana, 2003). Currently about 150 GSA buildings are using the CMMS. The system has been used to keep track of how many work orders are left and how long they take to be done.

<u>Monitoring and Control</u>

WebCTRL™ is a front-end workstation system for building automation that facilitates data communication between terminals and the main computer with multiple standard and non-standard protocols. WebCTRL™ communicates with building components directly with or from the EMCS. From any web browser, users can monitor the data in real-time and create time-series graphics. The data typically monitored are whole building electric demand, gas usage, outside air temperature, chilled water temperature and flow, cooling energy, and space temperatures. WebCTRL™ also facilitates remote control of set points through web browser.

GEMnet has a monthly utility bill data archive and analysis tool. It summarizes current and historical electricity and gas consumption and cost. The energy data are compared with average energy index of the group of buildings categorized by area and building use. GSA is also currently testing some diagnostic tools for future incorporation into GEMnet. These tools diagnose system problems and poor performance based on a combination of parameters obtained from EMCS data.

Diagnostics

GSA is currently testing a diagnostic tool, PACRAT, a database software tool for utilizing EMCS trend data to improve facility operations and planning. PACRAT diagnoses system problems and poor performance based on combination of parameters obtained from EMCS data. When identified an anomaly, it diagnoses the possible cause and provide a solutions. PACRAT also identifies energy wastes by estimating energy usage of the optimal operation (Friedman, 2001).

Costs

Table 6 shows the costs of the EIS installation for each system. The costs of particular categories may not be comparable because of different system architectures and installation processes. Differences between commercial products and research demonstration may influence the costs as well. The cost of GEMnet is not provided because it is still under development and it is difficult to quantify its cost.

Table 6. EIS Costs

Site	**UCSB***	**Sansome**	**925L**
EIS	EEM Suite™	IMDS	IMDS
Software	$181,000	$12,500	$16,000
Sensors	$50,000	$41,500	$23,500
Other hardware	$12,000		$12,500
Installation/setup	$52,000	$73,000	$73,000
Networking	$11,500	$9,000	$9,000
Total	**$306,500**	**$136,000**	**$134,000**
$/sqft	**0.10**	**1.36**	**0.77**

* Maintenance and support fee is not included.

The system value of the 925 L IMDS is approximately $50,000. The system costs were brought down from $63,000 for the pilot IMDS due to the drop in prices for computer and network technology and the use of lower-grade sensors. Costs per square foot are $0.10 for UCSB, $1.36 for 160 Sansome, $0.77 for 925 L. The reasons for the lower cost per square foot for UCSB are; 1) UCSB has multiple buildings and larger total square footage than the other case studies, and 2) main monitored points at UCSB are electric meters which are inexpensive to purchase and install, while many higher accuracy sensors were installed at 160 Sansome and 925 L.

Summary and Future Directions

This paper has reviewed the use of and concepts behind advanced energy information systems and related technologies at several buildings. Significant energy savings were attributed to the energy information and related systems at numerous buildings. The simple payback time for the EIS at UCSB was about one year. Non-energy benefits from EIS and related technology include improved operators productivity, better comfort and reduce tenant complaints, improved equipment lifetime from reduced cycling of EIS, and a better overall understanding of building performance.

Energy Information Systems and related technologies will play a growing role in helping to manage and minimize energy costs. Future systems will be integrated with building system control, maintenance, and tenant feedback. Researchers and technology developers need to evaluate how to best utilize such new technology and the growing volume of data they offer. Opportunities exist to automate the detection of anomalies in energy consumption patterns and operational data through the use of fault-detection and diagnostic systems. Methods to digest and present information in condensed graphical analysis are also desirable to help operators interpret massive operational data more easily.

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